American Journal of Infection Control 44 (2016) e195-e203

Contents lists available at ScienceDirect

American Journal of Infection Control

journal homepage: www.ajicjournal.org

Major Article

Copper alloy surfaces sustain terminal cleaning levels in a rural hospital

Shannon M. Hinsa-Leasure PhD [a,b,*], Queenster Nartey BA [a], Justin Vaverka BA [a], Michael G. Schmidt PhD [a]

[a] Department of Biology, Grinnell College, Grinnell, IA
[b] Department of Microbiology and Immunology, Medical University of South Carolina, Charleston, SC

Key Words:
Antimicrobial copper
Health care-associated infections
Infection control
Bacteria burden
Built environment

Objective: To assess the ability of copper alloy surfaces to mitigate the bacterial burden associated with commonly touched surfaces in conjunction with daily and terminal cleaning in rural hospital settings.
Design: A prospective intention-to-treat trial design was used to evaluate the effectiveness of cooper alloy surfaces and respective controls to augment infection control practices under pragmatic conditions.
Setting: Half of the patient rooms in the medical-surgical suite in a 49-bed rural hospital were outfitted with copper alloy materials. The control rooms maintained traditional plastic, metal, and porcelain surfaces.
Methods: The primary outcome was a comparison of the bacterial burden harbored by 20 surfaces and components associated with control and intervention areas for 12 months. Locations were swabbed regardless of the occupancy status of the patient room. Significance was assessed using nonparametric methods employing the Mann-Whitney U test with significance assessed at $P < .05$.
Results: Components fabricated using copper alloys were found to have significantly lower concentrations of bacteria, at or below levels prescribed, upon completion of terminal cleaning. Vacant rooms were found to harbor significant concentrations of bacteria, whereas those fabricated from copper alloys were found to be at or below those concentrations prescribed subsequent to terminal cleaning.
Conclusions: Copper alloys can significantly decrease the burden harbored on high-touch surfaces, and thus warrant inclusion in an integrated infection control strategy for rural hospitals.

INTRODUCTION

A major concern of health care is the prevalence and substantial acquisition rate with which health care-associated infections (HAIs) occur. In the United States, there are approximately 35.1 million discharges resulting from in-patient care. It is estimated that the rate of HAI acquisition is 1 out of every 25 patients admitted.[1] For 2011, it is estimated that of the approximate 722,000 patients who contracted HAIs, 10% died as a consequence of this adverse event subsequent to hospitalization.[1] The Patient Protection and Affordable Care Act has generated both enhanced scrutiny and added consequence to this alarming rate. Of the more than 3,300 US hospitals evaluated by the Centers for Medicare and Medicaid Services, approximately 23% will lose some funding from Medicare as a consequence of the Hospital Acquired Condition Reduction Program or a so-called quality of care penalty being mandated by section 3008 of the law.[2] Accordingly, HAIs represent a substantial challenge to the industry both in terms of lives influenced and the added financial burden of health care.

Recent interest has focused on high-touch surfaces throughout the hospital and the ability of these surfaces to serve as reservoirs for pathogenic microorganisms, including *Staphylococcus aureus*, *Clostridium difficile*, and vancomycin-resistant enterococci.[3-7] These and other nosocomial pathogens have been found to survive from days to months on dry surfaces, such as those commonly found in hospital settings.[8] Although several different cleaning regimens have

* Address correspondence to Shannon Hinsa-Leasure, PhD, Department of Biology, Grinnell College, 1116 8th Ave, Grinnell, IA 50112.
E-mail address: hinsa@grinnell.edu (S. Hinsa-Leasure).
Work conducted by SH-L, QN, and JV was supported by Grinnell College. MGS was supported by the Medical University of South Carolina.
Conflicts of interest: M.G. received an unrestricted award to conduct research on efficiency of copper surfaces in healthcare settings from Olin Brass.

http://dx.doi.org/10.1016/j.ajic.2016.06.033

been tested, bacteria have been shown to repopulate hospital surfaces, making it very difficult to maintain the current suggested standard for surface-level cleanliness subsequent to terminal cleaning; that is, between 2.5 and 5.0 CFU/cm^2.[3,9-12]

Copper alloys, which are recognized by the Environmental Protection Agency (EPA) as having antimicrobial effectiveness, have been shown in vitro and in vivo to significantly and continuously reduce the number of bacteria, viruses, fungi, and yeasts compared with standard noncopper surfaces.[13-21] Copper alloy surfaces have been shown to kill a majority of bacteria within 2 hours of contact and recent studies have provided insight to the multicomponent mechanism of action attributed to copper on gram-positive and gram-negative bacteria.[22-28] Thus, hospitals are installing these metal surfaces, which are naturally antimicrobial, to decrease the prevalence of microbial pathogens within the built environment.

Recent clinical studies have demonstrated the effectiveness of copper alloy surfaces to reduce the bacterial burden and lower the rate of HAIs, with particular attention to surfaces associated with the built environment of medical intensive care units.[3,9,29-33] However, more than half of HAIs are acquired outside of an intensive care unit.[1] This study expands on previous work to determine the effectiveness of copper alloy surfaces for their ability to sustain the terminal cleaning standard in medical and surgical suite patient rooms, en-suite bathrooms, and 5 other high-touch surfaces external to patient rooms in a rural hospital. Both occupied and unoccupied medical-surgical rooms were studied to determine the background bacterial concentrations or burden. We hypothesized that through the introduction of copper alloy fixtures, furnishings, and equipment, bacterial loads associated with these highly touched surfaces would be sustained at or near the level recommended upon completion of terminal cleaning.

MATERIALS AND METHODS

Study site

The study was conducted at the Grinnell Regional Medical Center (GRMC), which is a 49-bed hospital located in Grinnell, IA. The medical-surgical suite included 18 patient rooms, with a total of 23 patient beds. Each patient room has an en-suite bathroom. A majority of the patients were ambulatory, regularly moving within their rooms, bathrooms, and hallways.

Cleaning regimen

Patient rooms were cleaned daily and were subjected to terminal cleaning upon patient discharge following the established protocol prescribed by the hospital. For the control rooms, High Dilution Disinfectant 256 (Spartan Green Solutions, Maumee, OH) was used for daily and terminal cleaning. For rooms with copper components (intervention arm) OxivirTB (Sealed Air Diversey Care, Charlotte, NC) was used for and daily and terminal cleaning. OxivirTB was used on the copper components to help maintain their appearance and to minimize bias as a consequence of appearance imperfections. There was no difference in efficacy of disinfection between the 2 disinfectants (data not shown). Rooms housing patients positive for *C difficile*, were subjected to an alternate disinfection protocol. Diffense (Spartan Chemical, Maumee, OH) or Clorox Bleach Germicidal Cleaner (Chlorox Company, Oakland, CA) was used to disinfect both the control and rooms with the copper alloy surfaces (intervention). All cleaners were used as prescribed by the manufacturers. All sinks and overbed tables were polished bimonthly with Wrights Copper Cream (Weiman, Gurnee, IL) to maintain the color and uniformity of finish, according to the manufacture's recommendations, because EPA-registered copper alloys are equivalently and continuously antimicrobial regardless of appearance.

Study design and sample collection

A prospective intention-to-treat trial design was used to evaluate the effectiveness of cooper alloy surfaces and the concurrent control surfaces under pragmatic conditions for an ability to augment existing infection control practices at GRMC. The primary outcome of the study was the bacterial burden associated with frequently touched surfaces in proximity to patients and patient care providers. GRMC has HAI acquisition rates too low for statistical comparisons.

The bacterial burden was measured by the weekly collection of samples from a total of 20 surfaces and objects, over the course of 12 months. Sampling was conducted as described by Attaway et al.[3] Upon recovery of the sample from each component, each wipe was placed into 3 mL PBS-LT (phosphate-buffered saline with 0.5% Tween80 and 0.07% lecithin). Samples were vortexed, diluted as necessary, and enumerated by plating onto TSA + 5% sheep's blood agar (TSAII; Becton Dickinson and Company, Sparks, MD) with subsequent incubation at 37°C for 48 hours.

Before the intervention 17 high-touch objects were sampled routinely over the course of a 10-week period before installation of surfaces and objects fabricated from or surfaced with, a copper-nickel alloy (C706) that contained 90% copper by weight (Fig 1). The patient rooms on a single side of the hallway in the medical-surgical suite were outfitted with listed components fabricated using EPA-registered copper alloys. There were 13 single rooms, 6 of which were outfitted with copper alloy components. Of the 5 double rooms, 3 contained copper alloy components.

All samples taken during the preintervention period were from occupied patient rooms. Following installation of the copper components, items were sampled in occupied and unoccupied rooms. An unoccupied room was defined as an empty patient room that had received terminal cleaning and was not housing a patient at the time of sampling. The date of the terminal cleaning was not collected. Although it is considered important, the sample size of the current study would not support our ability to assess significance. Rails associated with the medical-surgical unit beds were sampled from the control rooms. A copper equivalent medical-surgical unit bed was not fabricated for the intervention. The rails on a stretcher bed (7500 Guardian Series ± copper rails; Pedigo, Vancouver, WA) used by emergency departments and for patient transport were evaluated.

Additionally, 4 objects resident outside of patient rooms were studied, including sinks and faucet handles in staff lounges, keyboards located at nurse and physician stations, and American Disabilities Act automatic door opener push plates.

Statistical analysis

As a result of individualized care provided to patients, the microbial burden in the built clinical environment is not normally distributed on surfaces. Given this nonparametric distribution of the microbial burden resident on the surfaces sampled and the limited number of samples collected from each of the 39 components assessed (average, 21 occupied rooms and 18 unoccupied rooms), values exceeding the 99% confidence interval from within each component were excluded from analysis to account for the variability in the precision of sampling (SAS software, Version 9.4, Cary, NC). Of 1,392 samples recovered and enumerated, 42 of 871 collected from occupied rooms (4.95%) and 31 from the 551 components assessed from unoccupied rooms (5.95%) were deemed outliers and excluded from subsequent analysis. The final datasets were analyzed using the Mann-Whitney *U* test with a significance level at $P < .05$ using Prism 6 software (GraphPad Software, Inc, LaJolla, CA).

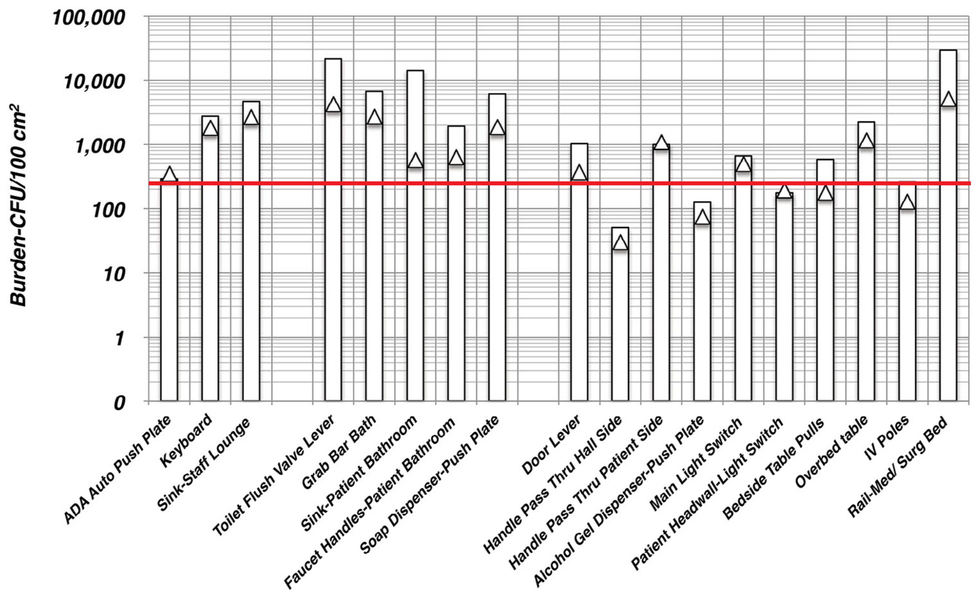

Fig 1. Distribution of bacterial burden associated with frequently encountered components within the built clinical environment routinely exceeds the concentration recommended subsequent to terminal cleaning. The average and median (△) (bottom of the triangle represents concentration) concentrations of bacteria recovered from frequently touched components over a 10-week period. The red line indicates the 250 CFU/100 cm^2 threshold concentration recommended for at-risk components immediately upon completion of terminal cleaning. Total items sampled = 133.

RESULTS

Distribution of bacterial burden associated with frequently encountered components within the built clinical environment routinely exceeds the concentration recommended subsequent to terminal cleaning

Before the intervention the bacterial concentrations associated with surfaces were determined for the objects both within and outside of occupied patient rooms (Fig 1). The average concentration of bacteria recovered from the 18 selected items was 5,438 CFU/100 cm^2 (n = 133; median concentration, 510 CFU/100 cm^2). Only 5 of the components were below the average concentration of bacteria recommended subsequent to terminal cleaning (250 CFU/100 cm^2) (Fig 1). The highest concentrations of were associated with bathroom surfaces. The toilet flush handles were found to have the highest average concentrations at 21,534 CFU/100 cm^2, a level 86 times higher than the concentration thought to be benign subsequent to terminal cleaning.

Copper alloys resulted in significantly reduced concentrations of bacteria on frequently encountered components sustaining levels prescribed on completion of terminal cleaning

Preintervention burdens were similar to levels observed from the components within occupied control areas during the interventional phase with a few exceptions. Two of the 18 objects had preintervention concentrations that were significantly lower; the grab bars within the en-suite bath were found to harbor on average 6,687 CFU/100 cm^2 before installation and averaged 36,916 CFU/100 cm^2 ($P = .0462$) during the course of the intervention; the sinks associated with the staff lounge were found to harbor on average 4,720 CFU/100 cm^2 before installation and an average 87,767 CFU/100 cm^2 ($P = .0105$) subsequent to installation. One component was found to have significantly higher preintervention concentrations: The control keyboards, external to the patient rooms, were found to harbor on average 2,758 CFU/100 cm^2 before the intervention and 1,212 CFU/100 cm^2 ($P = .0247$) postinstallation. A similar trend was observed on the toilet flush handles within the en-suite bath, which harbored on average 21,534 CFU/100 cm^2 before installation, whereas only 2,340 CFU/100 cm^2 ($P = .0516$) subsequent to the placement of copper within the unit.

Following installation a significant difference was observed ($P < .0001$) between the bacterial concentrations recovered from all of the copper components sampled as contrasted against the control items. An average concentration of 117 CFU/100 cm^2 (median, 0 CFU/100 cm^2; n = 654) was observed from all of the copper components sampled compared with an average of 6,172 CFU/100 cm^2 (median, 364 CFU/100 cm^2; n = 665) for the equivalent control components assessed collectively.

GRMC has an overall bed occupancy rate of 26.5%. Consequently, at any moment a substantial fraction of the rooms may be unoccupied—defined as a vacant room was vacant room that had received terminal cleaning after the prior occupant was discharged. In this study, approximately 63% of rooms were occupied at the time of sampling. When the data were considered separately, samples from both the occupied rooms and unoccupied rooms containing copper components were found to harbor significantly lower concentrations of bacteria than the concurrent controls ($P = .0001$) regardless of occupancy status (Table 1 and Fig 2). The overall mean concentration associated with the samples recovered from the occupied rooms, including those external to the patient's room, with copper components was 140 CFU/100 cm^2 (0 CFU/100 cm^2; n = 410) whereas the mean values associated with the concurrent controls was 8,414 CFU/100 cm^2 (median, 421 CFU/100 cm^2; n = 400) (Fig 2). The concentrations recovered from unoccupied rooms alone, were a mean concentration of 80 CFU/100 cm^2 (median, 0 CFU/100 cm^2; n = 244) for the copper components and a mean concentration of 2,434 CFU/100 cm^2 (284 CFU/100 cm^2; n = 246) for the concurrent controls (Fig 2). As expected, the burden associated with the components in unoccupied rooms was lower than occupied rooms. However, only the copper components were significantly lower than the equivalent occupied components ($P < .0001$) (Table 1). This observation was surprising because the

Table 1
Copper components sustained burdens near those prescribed for terminal cleaning regardless of occupancy status **** P ≤ 0.0001

Occupancy status	Copper components			Control components			
	Mean CFU/100 cm^2	Median CFU/100 cm^2	n	Mean CFU/100 cm^2	Median CFU/100 cm^2	n	P value
Occupied	161.7	0	303	5,368	345	298	<.0001*
Unoccupied	80	0	244	2,434	284	246	<.0001*
	Copper occupied	Copper unoccupied	P value	Control occupied	Control unoccupied	P value	
Mean CFU/100 cm^2	161.7	80	0.0001*	5368	2454	0.1331	
Median CFU/100 cm^2	0	0		345	284		

*$P \leq 0.0001$.

unoccupied rooms were cleaned immediately upon discharge with limited or no subsequent contact with the health care team, patients, or visitors (Table 1).

Copper alloys continuously sustained the terminal cleaning standard prescribed on completion of terminal cleaning, within vacant rooms

The overall utility of copper's ability to continuously control burden is illustrated by the frequency with which samples yielded a burden that was unrecoverable, between 1 and 250 CFU/100 cm^2, and exceeding 250 CFU/100 cm^2 (Fig 3). Here we learned that 88% of the samples collected from copper components from occupied areas where below the concentration recommended subsequent to terminal cleaning (250 CFU/100 cm^2), irrespective of when they were last terminally cleaned. The inverse was observed for the burden from the concurrent controls; 55% of samples were above this threshold. Values from the unoccupied rooms evaluated in this manner (Fig 3) showed 93% of the copper samples below this threshold, whereas 51% of the control samples were above this concentration. Of most concern where the grab bars in the en-suite baths, where each sample exceeded 250 CFU/100 cm^2, whereas those surfaced with copper were at or below concentrations prescribed upon completion of cleaning (Fig 3). Further evaluation of the unoccupied rooms revealed that more than 50% of overbed tables, soap dispenser push plates, main light switch plates, faucet handles, toilet flush handles, and sinks harbored bioload levels exceeding concentrations deemed acceptable after terminal cleaning, whereas none of the correlating copper surfaces harbored such high levels. Collectively, these observations warrant further exploration and suggests the value that continuously active antimicrobial materials can offer to enhance infection control.

DISCUSSION

An ability to maintain burden at or near levels subsequent to target terminal cleaning levels is important to patient outcomes, specifically with respect to the risk of HAI acquisition. Salgado et al[30] established that burdens associated with 6 high-touch objects in proximity to patient care that were collectively in excess of 500 CFU resulted in an increased likelihood that patients resident in such rooms had higher HAI acquisition rates. This study afforded us an opportunity to consider the performance of the continuously active antimicrobial properties of copper for its ability to augment existing infection control practices, specifically for its ability to extend the benefits of terminal cleaning. Unique to this study was the larger number of components evaluated and the remarkable finding that the continuously antimicrobial properties of surfaces fabricated using EPA-registered copper alloys were able to control the burden on many critical touch surfaces at or near the concentration suggested subsequent to terminal cleaning. This finding confirmed previous observations from other studies.[34-36] Of 654 copper components sampled over the course of the study, 89% were found at or below this targeted threshold of 250 CFU/100 cm^2 compared with only 44% of the 665 samples recovered from concurrent controls.

Analysis of the burden data by location of surfaces enables easy visualization of the value that copper surfaces can afford hospitals in maintaining burden associated with the built environment at these lower, less risky concentrations, independent of when components and surfaces were last subjected to terminal cleaning. The categories include those around the patient, associated with the en-suite bath, and within the unit (Fig 4). The majority of all of the control components sampled in the delineated areas were above the threshold of risk, 250 CFU/100 cm^2 regardless of occupancy status (Fig 4). The mean concentration of bacteria associated with the control components within the occupied en-suite bath were alarmingly high (13,093 CFU/100 cm^2 for the grab bars around the toilet, the toilet-flush handle, and the sink and its faucet handle) compared with the concentrations recovered from the copper components (183 CFU/100 cm^2; $P < .0001$). Grab bars carried the highest bacterial loads with an average concentration of 36,916 CFU/100 cm^2 in occupied, control rooms and 10,077 CFU/100 cm^2 in unoccupied control rooms. This observation highlights the need for environmental services to pay additional attention to all areas of the hospital associated with patient care.

Previous studies have shown similarly high bacterial burdens on bed rails, and when the control rails were assessed they too had similar average concentrations (8,177 CFU/100 cm^2) to those previously reported.[9,35] Surfaces with the lowest bacterial burdens on noncopper objects included alcohol dispensers, pass-through door handles (hallway side), headwall light switches, and push plates. Further study is recommended for these items to determine whether replacement of items with copper alloy surfaces is warranted in other hospital environments.

We expected to find decreased bacterial concentration on high-touch surfaces in occupied rooms compared with unoccupied rooms that had been terminally cleaned. Our most surprising results came when we analyzed bacterial burdens on control surfaces in unoccupied noncopper patient rooms. The bacterial burden on terminally cleaned and unoccupied control rooms exceeded the 250 CFU/cm^2 level of risk on 51% of surfaces. This observation confirms the observations made by Attaway et al[3,34] that describe the reestablishment of a microbial population onto hospital surfaces subsequent to cleaning. Carling and Hwang, in their 2013 commentary,[37] highlight lapses in procedures for, and quality of, health care cleaning and disinfection despite the presence of institutional policies consistent with national guidance with data presented here reinforcing this risk. The burden recovered between the 2 groups from both occupied areas and unoccupied control rooms well illustrates that despite adherence to the cleaning protocols there exists an omnipresent risk from microbial burden resident in the environment. However, the introduction of

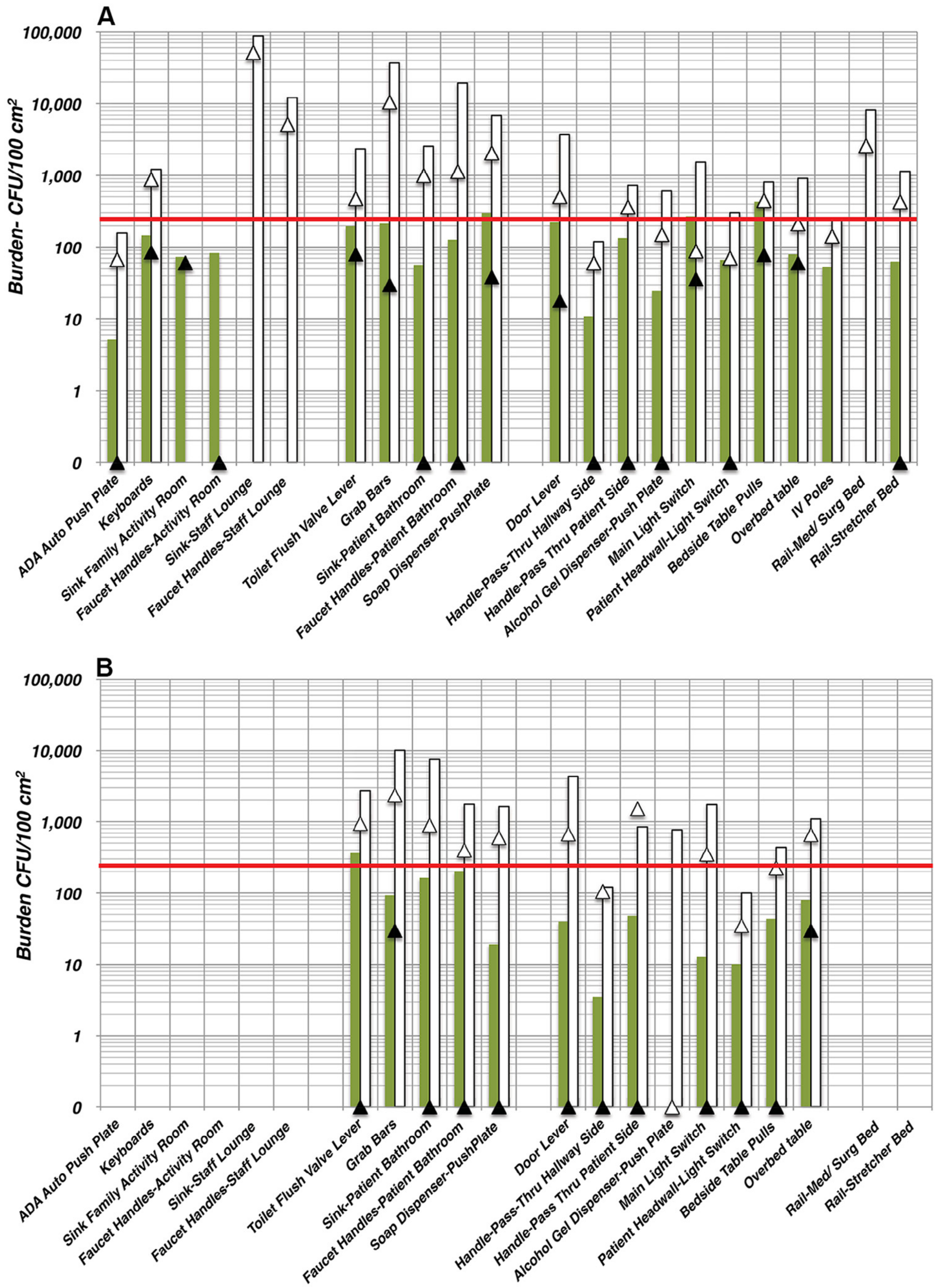

Fig 2. Copper alloys significantly reduced concentrations of bacteria on frequently encountered components, sustaining levels prescribed upon completion of terminal cleaning. (A) The average and median of bacteria recovered from frequently touched components from occupied rooms from Grinnell Regional Medical Center once weekly for a period of 1 year are reported. The red line indicates the 250 CFU/100 cm^2 threshold concentration recommended for at-risk components immediately upon completion of terminal cleaning. The green bars represent the mean concentrations of the copper alloy components and surfaces sampled ($n = 410$). The black triangles represent the median concentration observed, the white bars the concentrations recovered from the control surfaces and components ($n = 419$), and the white triangles represent the median concentration observed. (B) The mean and median concentrations from unoccupied rooms for copper ($n = 242$) and control ($n = 246$) components using the same notation as in A.

copper components offers hospitals an opportunity to comply with the 2010 Centers for Disease Control and Prevention guidance that recommends that hospitals not only obtain a high compliance rate with surface cleaning, but also move simultaneously to develop a program involving a system for an objective ongoing monitoring of cleaning practices to use such data in structured educational interventions within the institution (level 2).[38] Here we argue that the consistency with which copper components were able to sustain the terminal cleaning standard offer another justification as to the value that copper can provide to an integrated systems-based approach to infection control. Further, the significant decrease to burden recovered from common items encountered during routine patient care is important to health care because it not only decreases the exposure of patients to potential pathogens in their immediate surroundings, but also, due to the inherent DNA damage mediated by contact with copper, these alloy surfaces can decrease the likelihood of horizontal gene transfer amongst antibiotic-resistant microbes.[25-28]

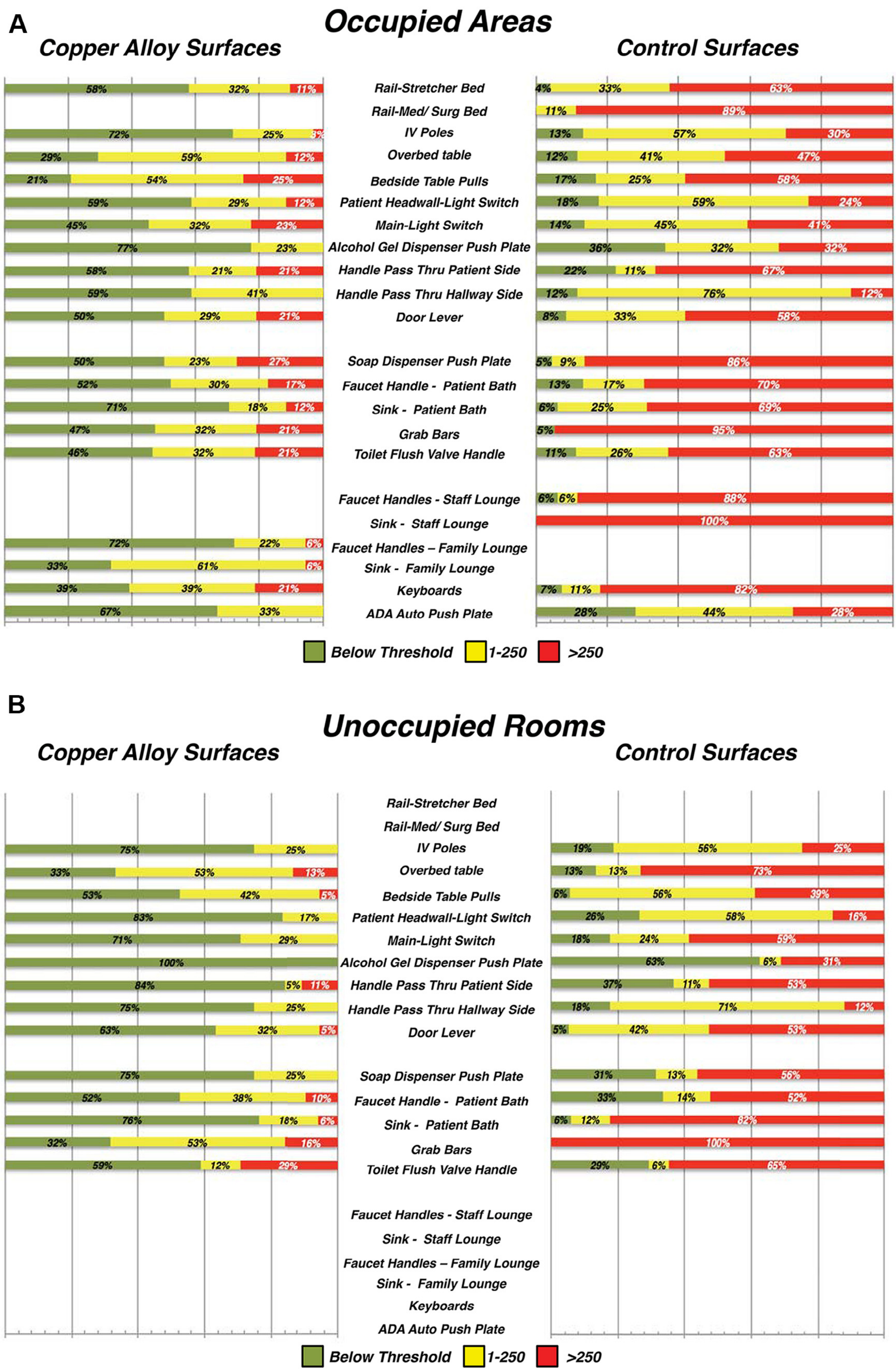

Fig 3. Copper alloys were frequently able to sustain bacterial concentrations at or near those prescribed upon completion of terminal cleaning. The distribution frequency (%) that individual samples associated with the listed copper or control rooms reported as CFU/100 cm^2. (A) Occupied rooms, n = 410, control rooms, n = 419. (B) Unoccupied rooms, n = 242 and control rooms, n = 246).

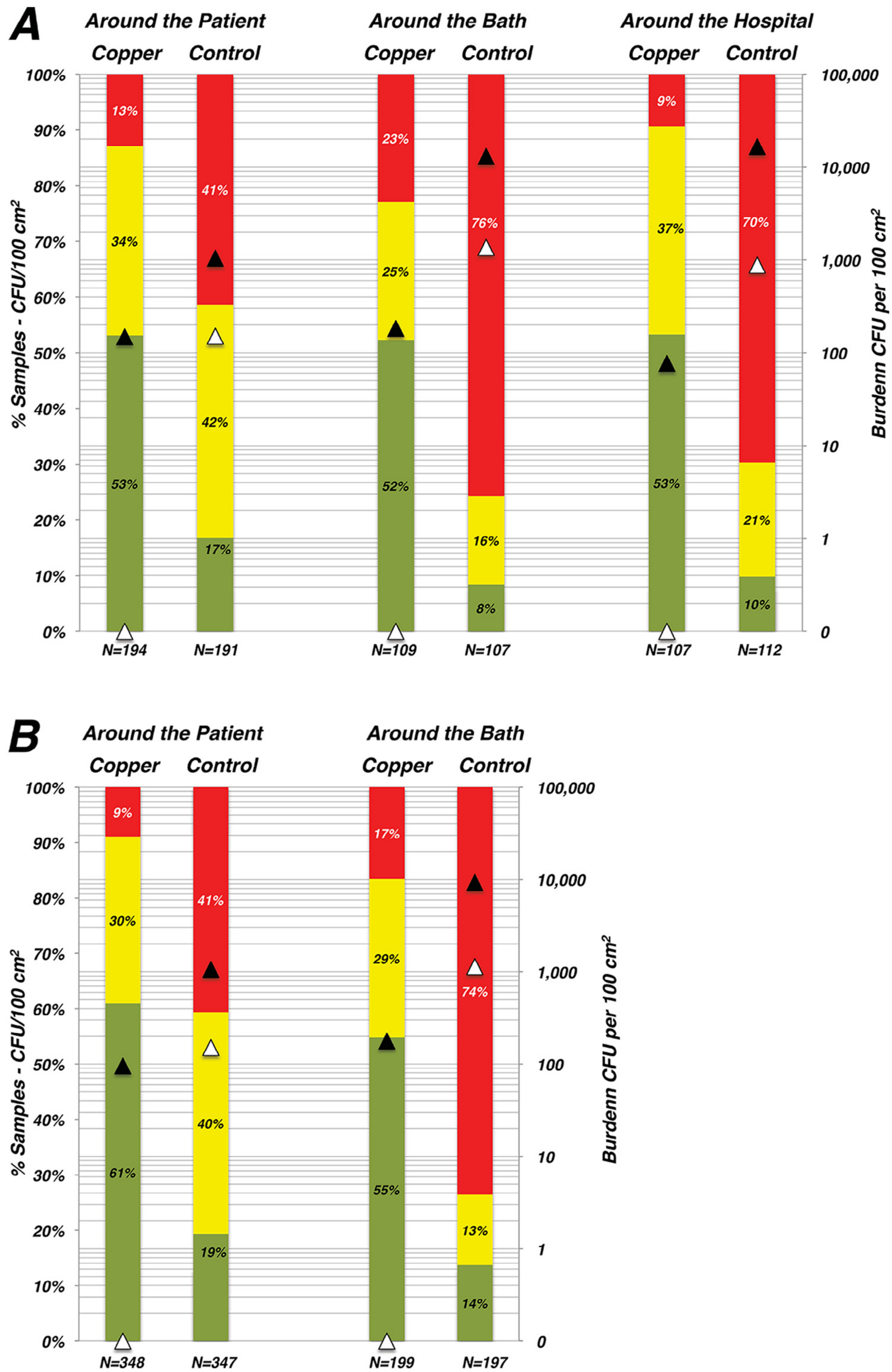

Fig 4. Copper alloys resulted in significantly reduced concentrations of bacteria throughout the patient care setting, sustaining levels prescribed upon completion of terminal cleaning. The mean concentration (black triangles), the median concentration of burden (white triangles) observed and the distribution frequency (%) that concentration range of burden was recovered from samples associated with the copper components and control components associated with occupied rooms (A) and all locations sampled regardless of room occupancy status (B) reported as to location. Green represents bacteria burdens below detection, yellow represents 1-250 CFU/100 cm^2, red represents >250 CFU/100 cm^2. Around the patient items sampled: alcohol push plate, door levers, handle, pass thru hall side, handle pass-through patient side, main room light switch, headwall light switch, overbed table top, bedside table pulls, and intravenous line pole. Around the bath items sampled: grab bars, toilet flush handle, patient sink, patient faucet handle, sand oap dispenser push plate. Around the unit items sampled: Americans with Disabilities Act push plate, keyboard, emergency room rail stretcher bed, and staff sink (control only), staff faucet handles (control only), family lounge sink, and family lounge faucet handles (copper only).

Although it has been reported from a number of studies that antimicrobial copper surfaces can consistently achieve a 90% reduction in the concentration of bacterial burden on copper alloy surfaces, outliers were encountered. We addressed this by excluding from analysis concentrations outside of the 99% confidence interval. This resulted in 42 of 871 samples collected from occupied rooms (4.95%) being excluded and 31 from the exclusion of 551 components from unoccupied rooms (5.95%). This was done consistently and without bias. Patients were allowed to move freely throughout their room and en-suite bath during their hospital stay. Although copper can quickly inactivate an individual bacteria, the EPA public health label informs us that it can take up to 2 hours for copper to kill bacteria, we believe the variability observed in our measurements resulted from the ambulatory activities of patients.[19] It is also possible that bacterial spores were able to survive on copper alloy surfaces because studies have shown spores to be more recalcitrant to the antimicrobial properties of copper alloy surfaces.[39]

This study demonstrates the influence copper alloy surfaces can have on the burden harbored by common items within patient care settings. Most of the copper alloy surfaces went unnoticed by patients, except for the copper alloy sinks and over-bed tables, which stained easily. Both required additional labor for the cleaning staff to maintain their appearance. Once a method was implemented to mitigate and/or remove stains, patient and staff acceptance increased. Copper alloy components should become an important part of hospital infection control, working in concert with hand hygiene and daily and terminal cleaning.

Acknowledgments

The authors thank the Grinnell Regional Medical Center Hospital staff and environmental services team for providing expert assistance, support, and patience over the course of this study. The authors also thank T. Kelling and H.H. Attaway for support in sampling, and Peter A. Sharpe for thoughtful discussions. The copper components were provided at no cost to Grinnell Regional Medical Center through a cooperative arrangement between GBC Metals, LLC, d/b/a Olin Brass and their affiliates, including: AE Fund, Inc, d/b/a Frigo Design; AmFab, Inc; AS America, Inc, d/b/a American Standard Brands; ATEK Access Technologies, LLC—Larco Brand; Colonial Bronze Company; Eaton Wiring Devices; Elkay Plumbing Products Company; Gojo Industries, Inc; Just Manufacturing Company; Midbrook, LLC; MR Label Company; Operator Interface Technology; Pedigo Products, Inc; Rocky Mountain Hardware, Inc; Sloan Valve Company; Triangle Brass Manufacturing Company, d/b/a Trimco; and Tubular Specialties Manufacturing, Inc.

References

1. Magill SS, Edwards JR, Bamberg W, Beldavs ZG, Dumyati G, Kainer MA, et al. Multistate point-prevalence survey of health care-associated infections. N Engl J Med 2014;370:1198-208.
2. PUBLIC LAW 111 - 148 - PATIENT PROTECTION AND AFFORDABLE CARE ACT. Public Law 111-148. 111 ed2010.
3. Attaway HH 3rd, Fairey S, Steed LL, Salgado CD, Michels HT, Schmidt MG. Intrinsic bacterial burden associated with intensive care unit hospital beds: effects of disinfection on population recovery and mitigation of potential infection risk. Am J Infect Control 2012;40:907-12.
4. Shaughnessy MK, Micielli RL, DePestel DD, Arndt J, Strachan CL, Welch KB, et al. Evaluation of hospital room assignment and acquisition of *Clostridium difficile* infection. Infect Control Hosp Epidemiol 2011;32:201-6.
5. Wagenvoort JH, Sluijsmans W, Penders RJ. Better environmental survival of outbreak vs. sporadic MRSA isolates. J Hosp Infect 2000;45:231-4.
6. Lepelletier D, Perron S, Huguenin H, Picard M, Bemer P, Caillon J, et al. Which strategies follow from the surveillance of multidrug-resistant bacteria to strengthen the control of their spread? A French experience. Infect Control Hosp Epidemiol 2004;25:162-4.
7. Stiefel U, Cadnum JL, Eckstein BC, Guerrero DM, Tima MA, Donskey CJ. Contamination of hands with methicillin-resistant *Staphylococcus aureus* after contact with environmental surfaces and after contact with the skin of colonized patients. Infect Control Hosp Epidemiol 2011;32:185-7.
8. Kramer A, Schwebke I, Kampf G. How long do nosocomial pathogens persist on inanimate surfaces? A systematic review. BMC Infect Dis 2006;6:130.
9. O'Gorman J, Humphreys H. Application of copper to prevent and control infection. Where are we now? J Hosp Infect 2012;81:217-23.
10. Rai S, Hirsch BE, Attaway HH, Nadan R, Fairey S, Hardy J, et al. Evaluation of the antimicrobial properties of copper surfaces in an outpatient infectious disease practice. Infect Control Hosp Epidemiol 2012;33:200-1.
11. White LF, Dancer SJ, Robertson C. A microbiological evaluation of hospital cleaning methods. Int J Environ Health Res 2007;17:285-95.
12. Dancer SJ. How do we assess hospital cleaning? A proposal for microbiological standards for surface hygiene in hospitals. J Hosp Infect 2004;56:10-5.
13. United States Environmental Protection Agency. Antimicrobial Copper Alloys—Group I (EPA Reg. No. 82012-1). Available from: https://www3.epa.gov/pesticides/chem_search/ppls/082012-00001-20140826.pdf. Washington DC: United States of America; 2008. Accessed September 8, 2016.
14. United States Environmental Protection Agency. Antimicrobial Copper Alloys—Group II (EPA Reg. No. 82012-2). Available from: https://www3.epa.gov/pesticides/chem_search/ppls/082012-00002-20140826.pdf. Washington DC: United States of America; 2008. Accessed September 8, 2016.
15. United States Environmental Protection Agency. Antimicrobial Copper Alloys—Group III (EPA Reg. No. 82012-3). Available from: https://www3.epa.gov/pesticides/chem_search/ppls/082012-00003-20140826.pdf. Washington DC: United States of America; 2008. Accessed September 8, 2016.
16. United States Environmental Protection Agency. Antimicrobial Copper Alloys—Group IV (EPA Reg. No. 82012-4). Available from: https://www3.epa.gov/pesticides/chem_search/ppls/082012-00004-20140826.pdf. Washington DC: United States of America; 2008. Accessed September 8, 2016.
17. United States Environmental Protection Agency. Antimicrobial Copper Alloys—Group V (EPA Reg. No. 82012-5). Available from: https://www3.epa.gov/pesticides/chem_search/ppls/082012-00005-20080229.pdf Washington DC: United States of America; 2008. Accessed September 8, 2016.
18. United States Environmental Protection Agency. Antimicrobial Copper Alloys—Group VI (EPA Reg. No. 82012-6). Available from: https://www3.epa.gov/pesticides/chem_search/ppls/082012-00006-20090712.pdf. Washington DC: United States of America; 2009. Accessed September 8, 2016.
19. Grass G, Rensing C, Solioz M. Metallic copper as an antimicrobial surface. Appl Environ Microbiol 2011;77:1541-7.
20. Quaranta D, Krans T, Espirito Santo C, Elowsky CG, Domaille DW, Chang CJ, et al. Mechanisms of contact-mediated killing of yeast cells on dry metallic copper surfaces. Appl Environ Microbiol 2010;77:416-26.
21. Warnes SL, Keevil CW. Inactivation of norovirus on dry copper alloy surfaces. PLoS ONE 2013;8:e75017.
22. Lemire JA, Harrison JJ, Turner RJ. Antimicrobial activity of metals: mechanisms, molecular targets and applications. Nat Rev Microbiol 2013;11:371-84.
23. Noyce JO, Michels H, Keevil CW. Potential use of copper surfaces to reduce survival of epidemic meticillin-resistant *Staphylococcus aureus* in the healthcare environment. J Hosp Infect 2006;63:289-97.
24. Noyce JO, Michels H, Keevil CW. Use of copper cast alloys to control *Escherichia coli* O157 cross-contamination during food processing. Appl Environ Microbiol 2006;72:4239-44.
25. Warnes SL, Highmore CJ, Keevil CW. Horizontal transfer of antibiotic resistance genes on abiotic touch surfaces: implications for public health. MBio 2012;3.
26. Warnes SL, Caves V, Keevil CW. Mechanism of copper surface toxicity in *Escherichia coli* O157:H7 and *Salmonella* involves immediate membrane depolarization followed by slower rate of DNA destruction which differs from that observed for Gram-positive bacteria. Environ Microbiol 2012;14:1730-43.
27. Warnes SL, Keevil CW. Mechanism of copper surface toxicity in vancomycin-resistant enterococci following wet or dry surface contact. Appl Environ Microbiol 2011;77:6049-59.
28. Warnes SL, Keevil CW. Death and genome destruction of methicillin-resistant and methicillin-sensitive strains of *Staphylococcus aureus* on wet or dry copper alloy surfaces does not involve Fenton chemistry. Appl Environ Microbiol 2016;82:2132-6.
29. Schmidt MG, Attaway Iii HH, Fairey SE, Steed LL, Michels HT, Salgado CD. Copper continuously limits the concentration of bacteria resident on bed rails within the intensive care unit. Infect Control Hosp Epidemiol 2013;34:530-3.
30. Salgado CD, Sepkowitz KA, John JF, Cantey JR, Attaway HH, Freeman KD, et al. Copper surfaces reduce the rate of healthcare-acquired infections in the intensive care unit. Infect Control Hosp Epidemiol 2013;34:479-86.
31. Karpanen TJ, Casey AL, Lambert PA, Cookson BD, Nightingale P, Miruszenko L, et al. The antimicrobial efficacy of copper alloy furnishing in the clinical environment: a crossover study. Infect Control Hosp Epidemiol 2012;33:3-9.
32. Michels HT, Keevil CW, Salgado CD, Schmidt MG. From laboratory research to a clinical trial: copper alloy surfaces kill bacteria and reduce hospital-acquired infections. HERD 2015;9:64-79.
33. Mikolay A, Huggett S, Tikana L, Grass G, Braun J, Nies DH. Survival of bacteria on metallic copper surfaces in a hospital trial. Appl Microbiol Biotechnol 2010;87:1875-9.
34. Schmidt MG, Attaway HH, Fairey SE, Steed LL, Michels HT, Salgado CD. Copper continuously limits the concentration of bacteria resident on bed rails within the ICU. Infect Control Hosp Epidemiol 2013;34.

35. Schmidt MG, Attaway HH, Sharpe PA, John J Jr, Sepkowitz KA, Morgan A, et al. Sustained reduction of microbial burden on common hospital surfaces through introduction of copper. J Clin Microbiol 2012;50:2217-23.
36. Schmidt MG, von Dessauer B, Benavente C, Benadof D, Cifuentes P, Elgueta A, et al. Copper surfaces are associated with significantly lower concentrations of bacteria on selected surfaces within a pediatric intensive care unit. Am J Infect Control 2016;44:203-9.
37. Carling PC, Huang SS. Improving healthcare environmental cleaning and disinfection: current and evolving issues. Infect Control Hosp Epidemiol 2013;34:507-13.
38. Guh A, Carling P. Options for evaluating environmental cleaning. Atlanta GA: Centers for Disease Control and Prevention; 2010.
39. San K, Long J, Michels CA, Gadura N. Antimicrobial copper alloy surfaces are effective against vegetative but not sporulated cells of gram-positive *Bacillus subtilis*. Microbiologyopen 2015;4:753-63.